BEHAVIORAL THERMOREGULATION IN THE JAVELINA (*TAYASSU TAJACU*)

by

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ABSTRACT

The mechanisms of thermoregulatory control used by the javelina (Tayassu tajacu) during June and July (summer) were investigated in the Sonoran Desert at Tucson, Arizona. Physiological and behavioral mechanisms affecting thermoregulatory ability were analyzed using energy and water balance equations. Behavior is the most effective mechanism used by the javelina to maintain thermal equilibrium with the environment. The control of body temperature through respiratory vaporization of water was found to be especially uneconomical unless an appropriate microenvironmental situation had been selected behaviorally. Javelina were found to require water in the form of surface water or succulent vegetation to maintain water balance.

INTRODUCTION

The monogeneric family Tayassuidae, Order Artiodactyla, is represented in the United States by the javelina Tayassu tajacu (Linnaeus), one of the two extant species. The javelina, or collared peccary, is found in southwest Texas, southern New Mexico, southern Arizona, and is distributed more or less continuously through Mexico, Central America, and South America into Peru and Argentina (Walker 1964). In the tropical portion of the javelinas' range it is sympatric with the other species of the genus, the white lipped peccary Tayassu pecari G. Fischer.

Javelina are found in small herds averaging 8 individuals (Knipe 1956). Adults may obtain a weight of 30 kg. Females are polyestrus, giving birth to from one to three young, usually twice a year (Knipe 1956). Young may be observed any month of the year with a definite peak of reproduction occurring in July and August (Sowls 1965).

The large distribution of the javelina in the Americas indicates all-year tolerance to a wide range of environmental conditions. Of interest are the adaptive problems of a subtropical animal to an existence in the arid Sonoran Desert. The javelina is absent from the most arid portion of the Sonoran Desert, i.e., the western part of the Lower Colorado Valley division of Shreve in Shreve and Wiggins (1964), where the annual precipitation often falls below 3 inches; javelina range maps are furnished by Cockrum (1960) and Knipe (1956).

In the other better watered division of the Sonoran Desert in Arizona the species is represented by well sustaining populations.

This investigation was initiated to determine what mechanisms are used by the javelina to maintain thermal equilibrium with the environment during the hot dry period preceding the summer rains in the Sonoran Desert. Energy and water balance were investigated in terms of survival limits of the interdependent variables body temperature and water loss. The study was conducted at the University of Arizona farm in an enclosure modified to simulate actual environmental conditions (Lowe and Hinds 1971).

Research on the javelina has been conducted by members of the U.A. Cooperative Wildlife Research Unit (Sowls 1966, Schweinsburg 1969, Bigler 1964, Eddy 1959), and the Arizona Game and Fish Department (see Knipe 1956). These studies have provided an understanding of an animal which does not enjoy a wide distribution within the United States and has been virtually ignored out of its U. S. range.

The physiology of heat and water balance in desert mammals of intermediate and large size has been well reported by Schmidt-Nielsen (1964), MacFarlane (1964), Hart (1964), Taylor (1969) and others. Treatment of the physical system operating in the desert has been detailed by Sellers (1965), Hardy (1968), Porter and Gates (1969), and Gates (1962).

METHODS AND MATERIALS

Description of the Study Site

The environmental, behavioral, and physiological data presented here were collected at the University of Arizona farm on North Campbell Avenue in Tucson, using outdoor animal pen facilities of the Cooperative Wildlife Research Unit and the Arizona Game and Fish Department. The javelina pen used in the investigation (Figs. 1 and 2) was approximately 5 x 8 meters with the long axis oriented north and south, the top was 2 meters above ground level. The pen was constructed of chain link fence with a single entrance on the south end. Partitioning of the pen was accomplished through construction of a series of wire covered frame barricades ca. 1.2 meters in height. The barricades were designed to give the investigator a safe area in which to work, to deny water to the javelina, and to force the animals into the prescribed microenvironmental situation.

The northern half of the pen was thickly thatched with palm fronds to provide a well shaded area for investigation. This shade at noon typically accounted for a 58 percent reduction in solar radiation, and a 33 percent reduction in soil surface temperature. Two adult javelina, part of a captive herd maintained for research purposes, a 25.7 kg female and a 29.5 kg male, 3 and 4 years old respectively, were the primary experimental animals. Javelina in adjacent pens were used for comparative behavioral data. Data were collected during the months

Fig. 1. Holding pen and instrumentation.

Working area showing weighing crate, scale, wire barricades, and body temperature recorder.

of June and July 1970, during the hot dry season preceding the summer rains that began in late July.

Data Collection and Reduction

Data from three periods are presented here--June 29-30, July 7, and July 10-13. Each of these periods represents a set of conditions designed to observe and record the responses of adult javelina to a definite set of environmental conditions.

The 24 hour period from midnight June 29 to midnight June 30 was used as a control period. The javelina were given freedom of movement in the pen, adequate water (no food was offered during any trial period), and were observed in the same manner used in later stress periods. The wind velocity during the 24 hour control period varied from 0 to 4.5 kph (hourly readings at 2 meters), relative humidity varied from 18 percent at 1600 on June 29 to 46 percent at 0500 on June 30, and cloud coverage varied from 0 percent at 1000 June 29 to 30 percent at 1700 on June 29.

A 5 hour period on July 7 from 0700 to 12 noon was used to evaluate the javelinas' response to an unshaded (=open) situation. The animals were placed in the sun (=unshaded) with no water, and no means of escaping the radiation load of the environment. Wind velocities varied from 0 to 3 kph (hourly readings at 2 meters). Relative humidity varied from 35 percent at 0700 to 21 percent at noon. Cloud cover varied from 5 percent at 0700 to 0 percent at noon.

A 3 day period beginning July 10 at 0600 and continuing through July 13 at 0630 was used to evaluate the tolerance to prolonged desiccation, and the progressive effect of desiccation on thermoregulatory

ability. While wind velocity was generally within the range of 0-5 kph, the 3 day period was accompanied by gusty winds in the late afternoons, reaching 35 kph on July 12 at 1700. These winds are the precursors of thunderstorms typical of the summer rains in the Sonoran Desert. No precipitation was recorded at the study site during the investigation. Relative humidity varied from 14 percent at 1400 on July 10 to 53 percent at 0400 on July 11. Cloud coverage typically varied from 0-5 percent throughout the morning (0800-1200) to 30-40 percent in the late afternoons (1500-1900).

The three periods described above were selected from numerous other periods of observation during the study, on the basis that they best typified both the environmental conditions of the Sonoran Desert in summer, and the responses of javelina to these conditions.

On June 7, 1970 a body temperature telemetry unit (Sensory Systems Laboratory) was inserted next to the peritoneal cavity of the male javelina, for purposes of monitoring deep body temperature. The unit was calibrated before and after the investigation, with no correction necessary. The telemetry device, checked against rectal temperatures taken either with a YSI thermister or a Schultheiss rapid-adjusting thermometer, was found to average 0.15°C higher. The telemetry signal was recorded with a citizens band receiver and with a unit-matched recorder by Sensory Systems Laboratory (Fig. 2).

All-wave radiation measurements were made with a Beckman-Whitley total hemispherical radiometer (Gier-Dunkle 1951) and monitored with a Leeds and Northrup millivolt potentiometer. Net radiation was calculated from normal and inverted instrument measurements. Stoll-Hardy and Barnes radiometers both equipped with germanium filters were

Fig. 2. Recorder and citizens band transceiver used to monitor deep body temperature.

used to obtain surface temperatures. Solar beam data were obtained from the Institute of Atmospheric Physics located on the University of Arizona campus, and were measured with an Eppley pyrheliometer.

Air temperatures were measured using foil-shaded thermister probes (YSI model no. 401) secured to a mast at five levels (0.25, 0.5, 1.0, 2.0, 3.0 meters). Shaded thermometers were used to measure temperature at four levels in the soil (1.5, 2.5, 5.0, 10.0 centimeters). Relative humidity was measured using a Bendix battery psychrometer 0.25 meters above the ground surface. Wind velocity was measured using a hand held anenometer (Sciences Associates cat. no. 444). All measurements were made hourly when possible.

Respiration counts were made with the aid of a stopwatch for a full minute period. Behavioral data were transcribed whenever body temperature was recorded, and at any other time deemed necessary.

Water balance data were obtained by weighing the animal, before and after a trial period, in a handling crate on a portable Howe platform scale (U.S. Army model). Weights obtained by subtracting the weight of the handling crate did not vary more than ¼ lb (0.11 kg) or 0.4 percent of body weight, from weights obtained by weighing a drugged animal directly on the same scale. The ability of the experimental javelinas to return to water balance was measured by presenting a known amount of water to the animal and recording the quantity taken over a known period of time.

Data reduction was aided by the CDC 6400 computer, Computer Center, University of Arizona.

RESULTS AND DISCUSSION

Behavioral Adaptive Mechanisms

Behavior during the hot period of the midsummer clear day predicates avoidance of the solar beam for survival. The javelina can tolerate a full environmental radiation load for only 1-2 hours during the hottest time of day. Consistent use of daytime shade is the single most important behavioral adaptive mechanism displayed by the javelina.

The respiration rate of a stressed animal increases from 25 per minute in the early morning (0600) to 60-80 per minute by mid-morning (1000) to a maximum 140-160 at mid-afternoon (1500). Open mouth panting had usually commenced by 1100 hours during a stress period, and rarely occurred in an unstressed animal. Javelina in the pens, when able, splashed drinking water on their bodies thereby creating artificial evaporative cooling; whether this is done under field conditions is doubtful.

Javelina in the pens became very irritable and unmanageable when deprived of water in stress situations, and it was difficult to obtain water consumption measurements at the end of a trial period. Measurements indicate that the adult javelina could reclaim no more than 1 kg of body water in the first hour, and required 2-4 hours to return to water balance.

The three day experimental stress period (Table 1), in which the javelina was denied water, resulted in death; the animal showed progressive loss of thermoregulatory ability. Although death occurred,

Table 1

Soil surface and ambient air (0.25 m), temperature in the sun and in the shade with javelina deep body temperature for July 10-13, 1970.

Date	Time (MS)	Soil Surface Temperature in Sun (° C.)	Soil Surface Temperature in Shade (° C.)	Ambient Air Temperature in Sun (° C.)	Ambient Air Temperature in Shade (° C.)	Javelina Body Temperature (° C.)
10 July	0600	22.5	24.2	27.1	27.1	38.29
	0800	29.2	27.1	28.0	28.1	38.52
	1200	58.0	38.5	44.6	39.0	38.03
	1600	56.7	34.5	44.1	39.8	38.31
	2000	29.8	26.9	33.2	32.2	38.48
	2400	24.3	25.5	29.2	31.1	38.27
11 July	0400	24.3	24.3	23.3	23.9	38.03
	0800	29.0	27.5	30.2	29.7	37.74
	1200	62.0	37.4	43.0	39.9	38.08
	1600	57.1	32.3	42.3	38.1	38.27
	2000	30.4	28.0	34.2	32.1	38.75
	2400	28.0	25.3	27.4	27.2	38.65
12 July	0400	26.9	24.7	23.5	23.8	38.21
	0800	38.9	32.6	28.3	26.2	37.50
	1200	64.6	40.2	42.9	37.8	37.96
	1600	57.5	39.8	44.4	39.3	39.80
	2000	30.6	33.1	36.3	34.5	39.35
	2400	28.6	30.1	29.2	29.3	39.30
13 July	0400	23.1	23.2	22.3	23.0	39.13
	0800	39.6	33.2	27.8	25.3	38.64
	1200	58.3	39.8	42.6	39.6	---

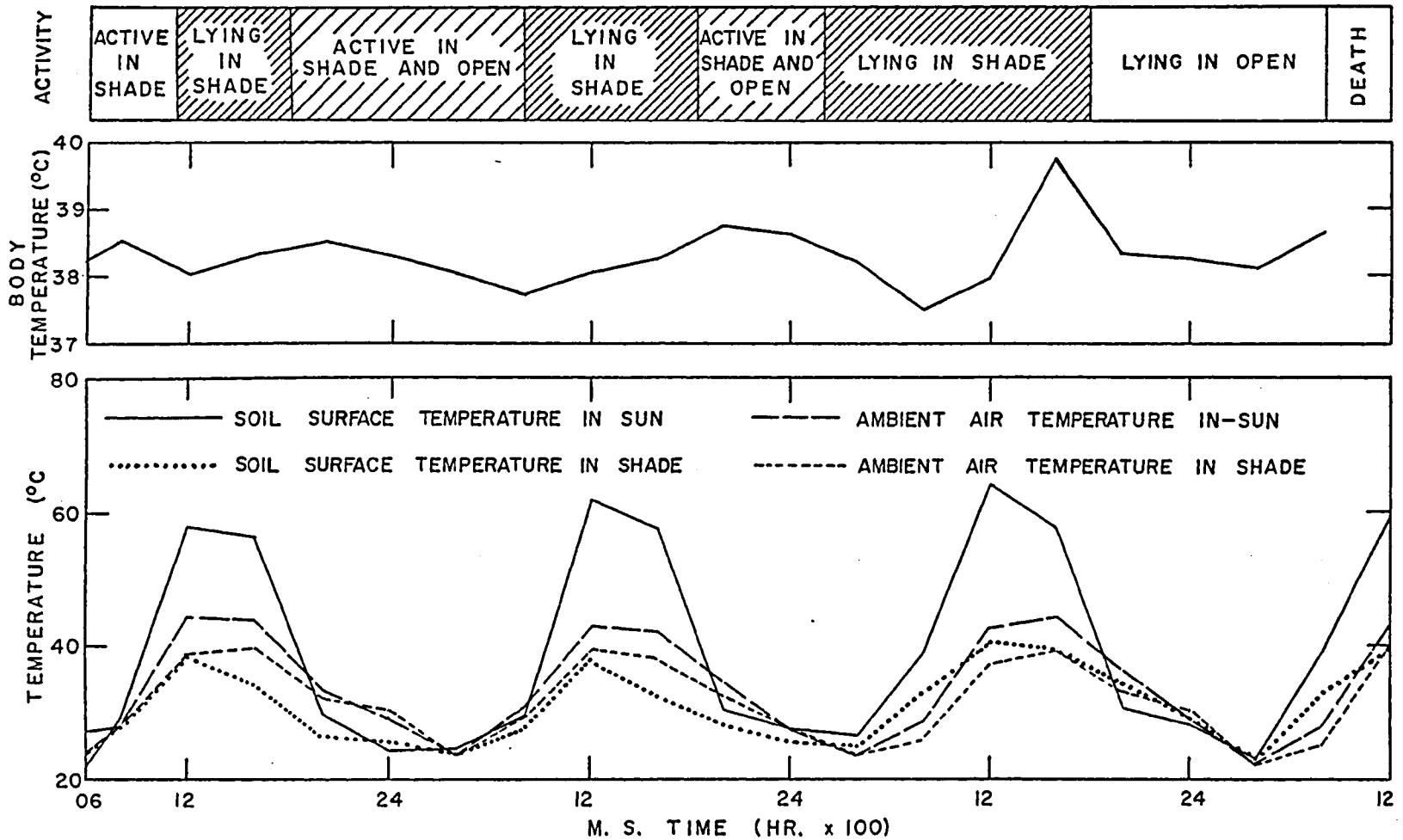

Fig. 3. Environmental temperatures and deep body temperature for July 10-13, 1970. Data in Table 1.

Soil surface temperatures and ambient air temperatures (0.25 m) in the sun and shade with body temperature and activity pattern.

body temperature never obtained the level reached in the unshaded stress situation (Fig. 1). At death the javelina displayed signs of salt poisoning (Bohstedt and Grummer 1954) presumably caused by concentration of salt through dehydration rather than a high salt content diet. On autopsy no gross pathological conditions were observed which could not have been due to severe dehydration (Kalvzniacki, pers. comm.).

During night activity the javelina in the open is able to raise metabolic heat production by 23,000 calories per hour, and still maintain energy balance. This accounts for the nocturnal activity pattern, since there is little cost to the animal in terms of water loss for the increased activity.

Energy Balance

The general ecology of the javelina has received considerably more attention than physiological and behavioral adaption to the desert. Behavioral adaption to hot dry summer conditions was observed by Schweinsburg (1969) and by Bigler (1964) while investigating social and territorial behavior, and seasonal activity of the javelina.

Physiologic mechanisms for control of body temperature were similar to those used by the dog (Schmidt-Nielsen 1964). Panting is a primary physiologic mechanism of body temperature regulation in both the javelina and the dog. Panting is efficient at high ambient temperatures and low relative humidities, and is well suited to survival under desert conditions. There was no indication of sensible water loss through the skin by the javelina.

Throughout the investigation the javelina showed the ability to regulate body temperature within well defined limits. Body temperature during the control period ranged from 37.91 to 38.55°C (Table 2), and was characteristically 0.5°C lower in the early morning compared to the late afternoon. The body temperature fluctuations observed were not sufficient to allow a significant heat storage in the body as compared to the camel (Schmidt-Nielsen 1964). In the final analysis, behavior was the most effective method used by the javelina to regulate body temperature.

Quantification of the behavioral contribution to body temperature regulation was accomplished through use of energy and water balance equations. The energy balance equations are modified from those of Porter and Gates (1969); energy terms were calculated to the nearest 1 Kilocalorie. Hour time units were used in the energy budget described by

$$M + Q_{abs} = T_r^4 = h_c(T_r - T_a) + E_{ex} \pm C,$$

Where M = metabolic heat production

Q_{abs} = absorbed radiation

T_r^4 = reradiation to the environment

$h_c(T_r - T_a)$ = forced convection

E_{ex} = heat loss through respiratory vaporization of water

C = conduction to substrate.

Kleiber (1961) expresses the basal metabolic heat production of homeotherms with the following formula:

$$M = 70W^{0.75},$$

where M is basal metabolic heat production in kilocalories per day,

Table 2

Ambient air temperature (0.25 m) in the shade and in the sun, with javelina deep body temperature for June 29 and 30, 1970.

Time (MS)	Air Temperature in Sun (0.25 m) (° C.)	Air Temperature in Shade (0.25 m) (° C.)	Javelina Body Temperature (T_B) (° C.)
1300	41.7	36.0	37.91
1600	42.3	36.2	38.15
1800	34.6	35.8	38.54
2000	29.0	28.6	38.55
2400	27.4	27.5	38.34
0400	22.3	22.1	38.03
0800	27.8	26.7	38.20
1200	40.0	35.1	38.19

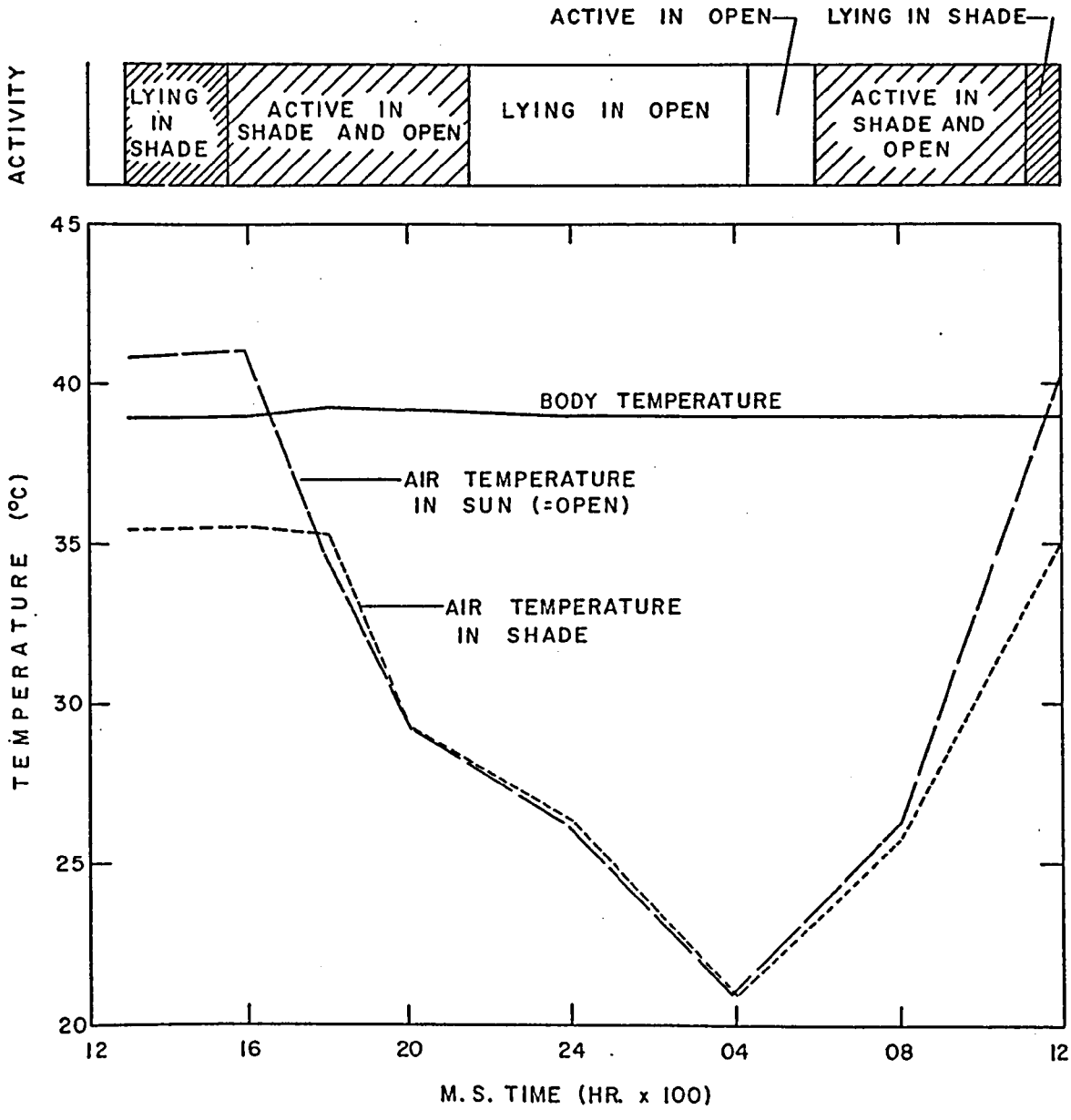

Fig. 4. Environmental temperatures and deep body temperature for June 29 and 30, 1970. Data in Table 2.

Javelina body temperatures and ambient air temperatures (0.25 m) in the shade and open, with activity pattern.

and W is weight in kilograms. A basal metabolic rate of 37,000 calories per hour was used (Appendix). Kleiber's (1961) formula for computing surface area (Appendix) was also used.

Porter and Gates (1969) define absorbed radiation with the following equation:

$$Q_{abs} = \frac{(a)(2/\pi)(S) + as + ar(S + s) + R_a + R_g}{2}$$

Where a = absorptivity, S = direct sunlight, s = reflected sunlight, r = reflectivity of soil, R_a = thermal radiation from sky, R_g = thermal radiation from ground.

Four environmental situations were considered; 1200-1300 unshaded, 1200-1300 shaded, 2400-0100 unshaded, 2400-0100 shaded. For purposes of calculation a = 0.70 (Porter and Gates 1969) was assumed to be a reasonable absorptivity during the day, while at night a = 1.0 was used since radiation is long wave radiation with very low reflectivity. Solar beam (= S) was obtained from The Institute of Atmospheric Physics (Table 3), and r was assumed to be 0.30 (Sellers 1965). Reflected solar radiation and thermal sky radiation were measured by shading from a distance the upright Gier-Dunkle plate, thereby eliminating the direct solar beam radiation; s was then taken to be 6 percent of the above measurement (Gates 1962) and thermal sky radiation was assumed to be the balance. Thermal ground radiation was calculated from the appropriate ground temperature (Table 4), assuming the ground to act as a 90% emitter (Sellers 1965).

Calculations of total absorbed radiation (Appendix) were made assuming the animal to be a cylinder of surface area 9,600 square

Table 3

Net all-wave radiation in the sun and in the shade with incident solar beam and javelina body temperature for June 29 and 30, 1970.

Time (MS)	Net Radiation in Sun (ly min^{-1})	Net Radiation in Shade (ly min^{-1})	Incident Solar Beam (ly min^{-1})	Javelina Body Temperature (T_B) (°C.)
1300	-----	+0.0774	1.39	37.91
1400	+0.7386	-----	1.29	38.07
1500	-----	+0.0779	1.18	38.17
1600	+0.6362	-----	1.01	38.15
1700	-----	+0.0475	0.67	38.33
1800	-0.0252	-----	0.35	38.54
1900	-----	+0.0032	0.08	38.57
2000	-0.1575	-----	--	38.55
2100	-----	-0.0164	--	38.40
2200	-0.0934	-----	--	38.43
2300	-----	-0.0282	--	38.43
2400	-0.0837	-----	--	38.34
0100	-----	-0.0330	--	38.19
0200	-0.0883	-----	--	38.29
0300	-----	-0.0339	--	38.24
0400	-0.0679	-----	--	38.03
0500	-----	-0.0753	--	38.08
0600	-0.0877	-----	0.06	38.10
0700	-----	+0.0159	0.32	38.15
0800	+0.1006	-----	0.63	38.20
0900	-----	+0.0675	0.91	38.22
1000	+0.6040	-----	1.14	38.24
1100	-----	+0.0930	1.22	38.12
1200	+0.8115	-----	1.33	38.19

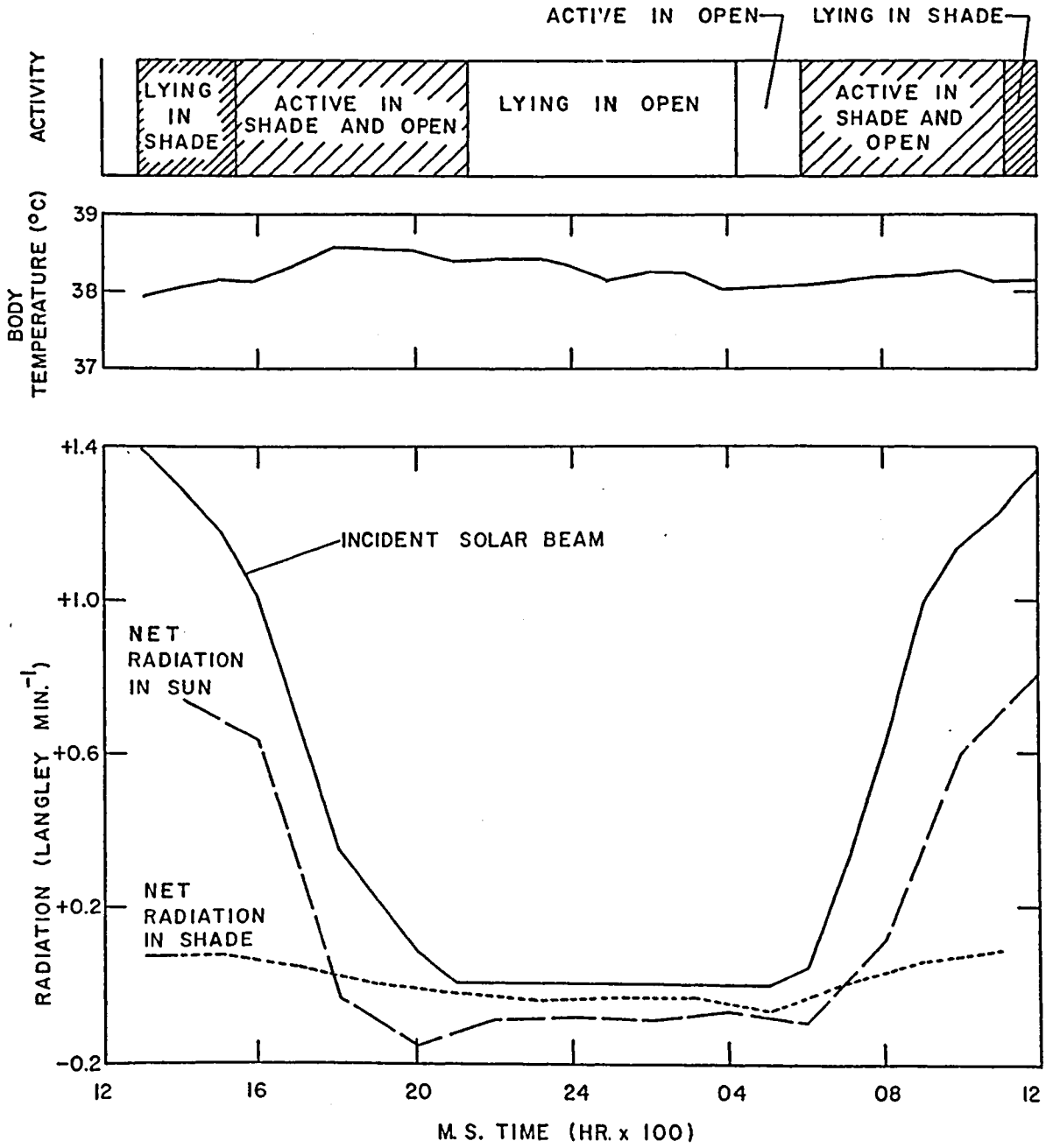

Fig. 5. Environmental radiation and deep body temperature for June 29 and 30, 1970. Data in Table 3.

Net all-wave radiation in the sun and in the shade with incident solar beam, body temperature, and activity pattern.

Table 4

Soil surface temperature in sun and shade, with javelina deep body temperature for June 29 and 30, 1970.

Time (MS)	Soil Surface Temperature in Sun (° C.)	Soil Surface Temperature in Shade (° C.)	Javelina Body Temperature (° C.)
1300	64.3	36.0	37.91
1600	57.1	37.3	38.15
1800	37.7	30.2	38.54
2000	30.4	28.0	38.55
2400	28.0	25.3	38.34
0400	24.3	24.3	38.03
0800	31.3	24.6	38.20
1200	56.0	37.4	38.19

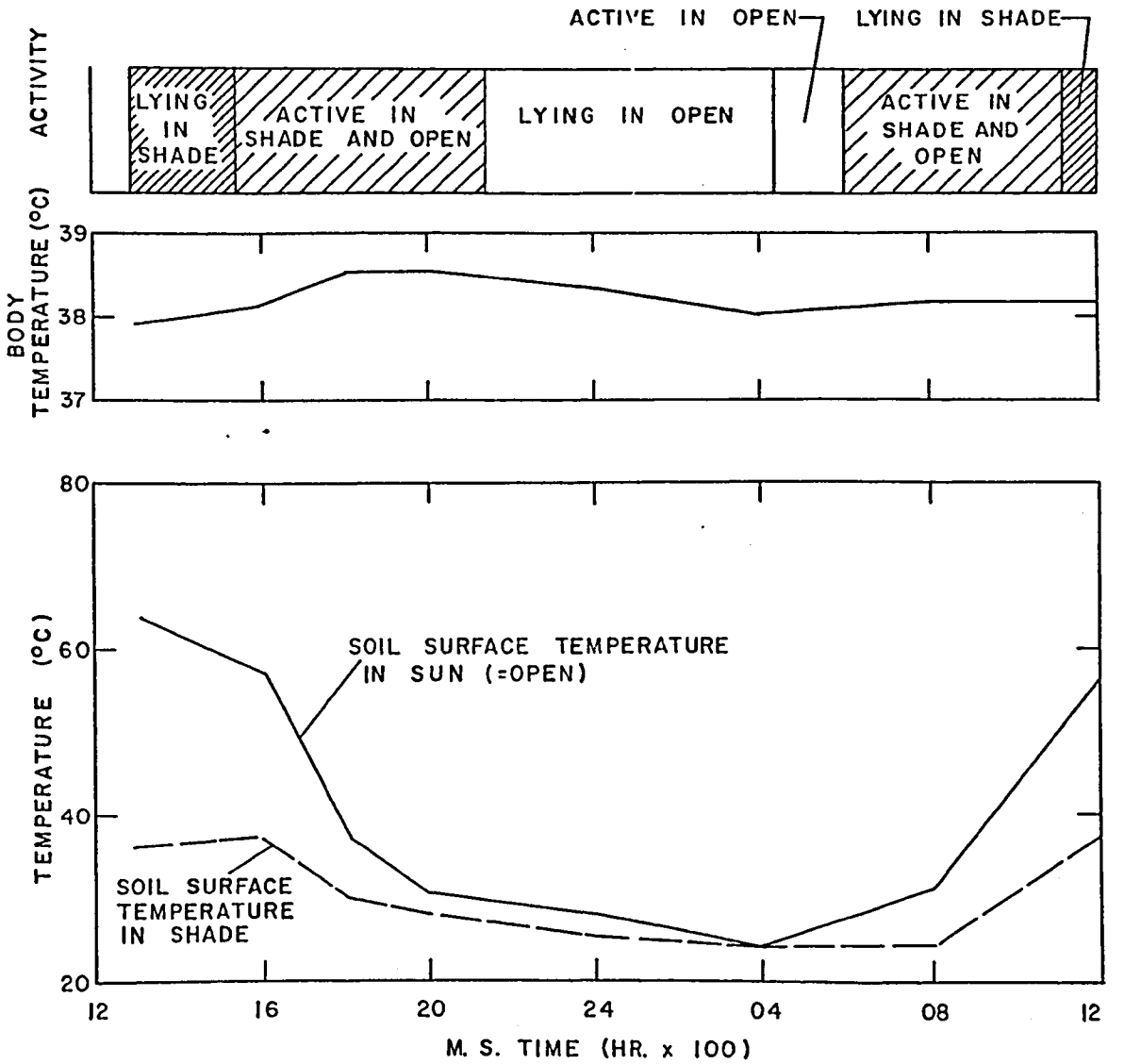

Fig. 6. Soil surface temperatures and deep body temperature for June 29 and 30, 1970. Data in Table 4.

Javelina body temperature and soil surface temperatures in the shade and sun, with activity pattern.

centimeters (Kleiber 1961). Total Q_{abs} was found to be: 751,000 calories per hour (1200-1300 unshaded), 511,000 calories per hour (1200-1300 shaded), 339,000 calories per hour (2400-0100 unshaded), and 354,000 calories per hour (2400-0100 shaded).

Reradiation from the javelina was calculated for the appropriate radiant surface temperatures (Appendix), and were found to be: 479,000 calories per hour (1200-1300 unshaded), 449,000 calories per hour (1200-1300 shaded), 395,000 calories per hour (2400-0100 both shaded and unshaded).

Forced convection is defined as $h_c(T_r - T_a)$, where h_c = coefficient of convection, T_r = radiant surface temperature of the javelina, and T_a - ambient air temperature. The coefficient of convection for a smooth cylinder (Gates 1962) is $h_c = 6.17 \times 10^{-3} \frac{V^{1/3}}{D^{2/3}}$, where V equals wind velocity (centimeters per second), and D equals cylinder diameter (centimeters). Convective heat losses were calculated for a wind velocity of 105 centimeters per second (2.5 kph); D equals 34.0 centimeters (Knipe 1956). Forced convection losses were 5,000 calories per hour (1200-1300 unshaded), 6,000 calories per hour (1200-1300 shaded), 4,000 calories per hour (2400-0100 shaded), 4,000 calories per hour (2400-0100 shaded).

Conduction to substratum was recognized in the form of the animal lying on the ground (Fig. 7):

$$C = \frac{KA(T_2 - T_1)}{D},$$

where K = thermal conductivity of air

A = area of contact

Fig. 7. Behavioral use of shade by javelina.

Javelina utilizing the shaded portion of the pen, and also using a shallow excavation for improved substrate conduction.

T_2 and T_1 are the temperatures of the adjacent surfaces

D = the thickness of the conductor

The javelina would not lie down in the sun during the period 1200-1300, therefore conduction was not calculated for this situation. Conduction to the substratum resulted in a loss of 1.74 calories per square centimeter per hour (1200-1300 shaded), 8.70 calories per square centimeter per hour (2400-0100 unshaded), 10.98 calories per square centimeter per hour (2400-0100 shaded).

The energy budget (less respiratory water loss) of a javelina in the sun from 1200 to 1300 on a hot summer day in the Sonoran Desert was a 305,000 calorie per hour gain. The energy budget for the same animal during the same noon period in the shade resulted in a net gain of 90,000 calories per hour.

The energy budget for a javelina in an unshaded situation at night (2400-0100) resulted in a net loss of 23,000 calories per hour; during the same period an animal in the covered portion of the pen would have a net loss of 8,000 calories per hour.

Water Balance

A gram of water at 38°C which is vaporized in the respiratory tract requires 572 calories of heat (energy). The maximum rate of respiratory water loss in the javelina was determined to be 500 grams per hour. Some of this water is wasted by dribbling (Robinson and Lee 1941). The percentage of such waste is difficult to determine; it was estimated to be about 20 percent in the javelinas studied.

The animal in the sun at noon (1200-1300) must expend the maximum possible amount of water to attempt to maintain energy balance. If 400 grams of water at 572 calories per gram were lost via the respiratory tract a deficit of 77,000 calories per hour would still remain in the energy budget, sufficient heat to raise the body temperature 3°C in an hour. This was verified experimentally (Fig. 9).

The javelina in the shade at noon (1200-1300) was able to compensate for heat gain by expending 157 grams of water per hour. Experimentally javelina were found to lose ca. 2.3 kg of water per hot summer day in shaded conditions when denied water. This rate was maintained until death occurred at 18 percent loss of body weight (N = 1). The javelina at midnight (2400-0100) need not expend water for cooling to maintain energy balance in either the open or in a canopy modified environment.

The 60 percent reduction in water loss for cooling purposes realized by utilizing shade clearly demonstrates the contribution of behavior in water conservation. That the animal can tolerate well short periods of exposure to the full environmental summer heat load in the desert is due to its intermediate size (25-30 kg). The javelina must have access to succulents, other plants, and/or free water at a rate of 2.3 kg per day, even though it behaviorally minimizes water loss. The reduced occurrence of surface waters and decreased abundance of succulents (and preferred roots) in the more arid portions of the Sonoran Desert probably accounts for the javelinas absence from these areas.

Fig. 8. Shaded and open areas of the holding pen.

Shaded and open portions of the pen showing the comparative shading effect.

Table 5

Upper and lower hemispherical all-wave radiation with ambient air (0.25 m), soil surface, and javelina deep body temperatures for a 4 hour period in the sun July 7, 1970.

Time (MS)	Soil Surface Temperature (° C.)	Ambient Air Temperature (° C.)	Upper Hemisphere Radiation (ly min^{-1})	Lower Hemisphere Radiation (ly min^{-1})	Javelina Body Temperature (° C.)
0800	39.6	28.0	+0.6996	+0.6943	38.75
0900	50.0	30.6	+0.9993	+0.8117	38.72
1000	54.0	32.8	+1.5949	+1.0237	39.69
1100	58.6	39.2	-----	-----	41.39
1200	63.4	43.0	+2.0045	+1.1043	42.69

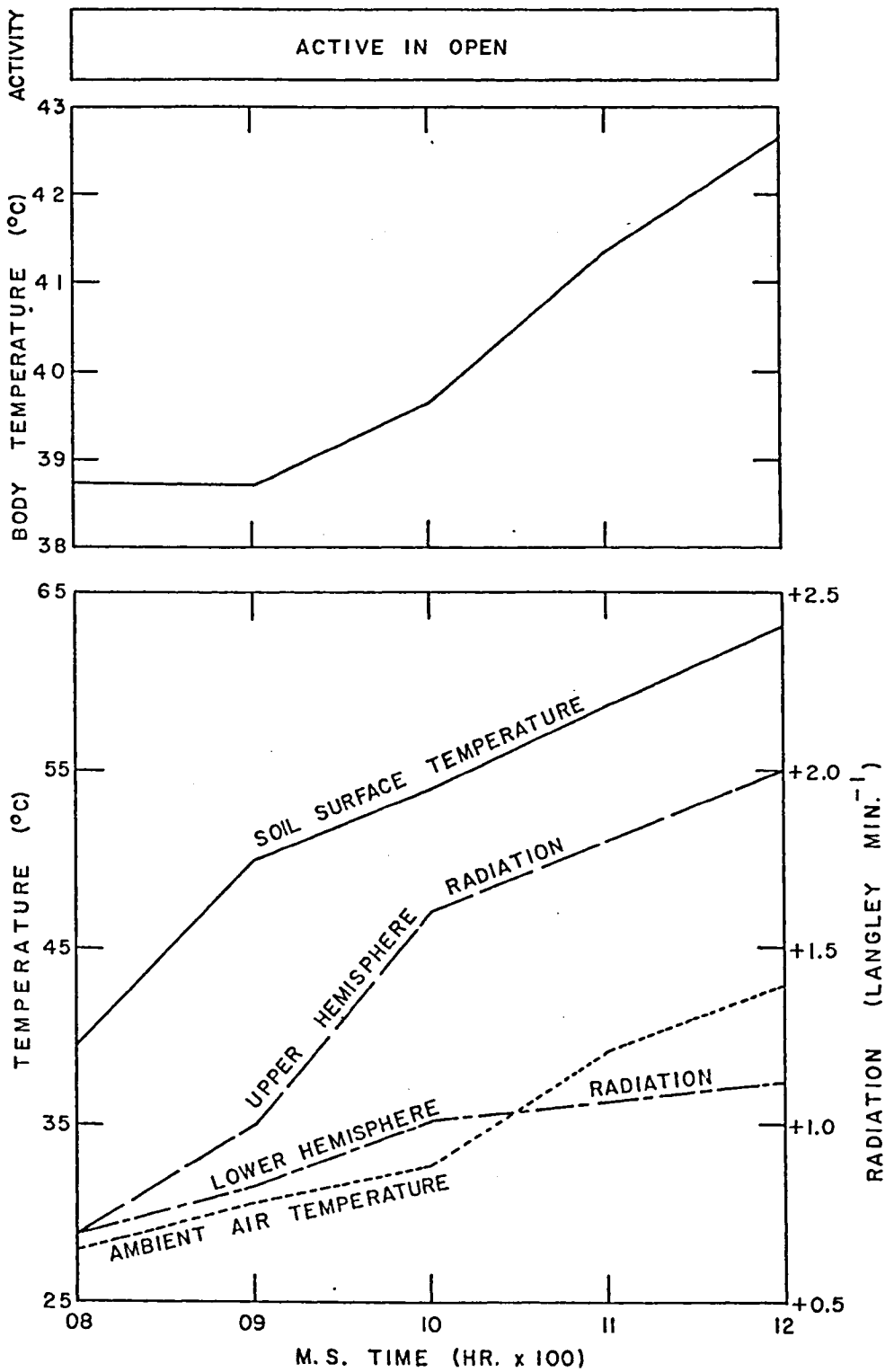

Fig. 9. Environmental radiation and deep body temperature for July 7, 1970. Data in Table 5.

SUMMARY AND CONCLUSIONS

The javelina is a subtropical mammal of intermediate size (25-30 kg) without special physiological adaptive mechanisms for desert survival during summer heat in the Sonoran Desert, and depends primarily on behavioral thermoregulation. The species requires free water either in the form of surface water and/or succulent vegetation including roots as a means of replenishing water required for thermoregulation. It is capable of losing up to 12 percent of body weight without noticeable effect; however, this amounts to only two days' survival under severe conditions. When water losses of greater than 12 percent of body weight are experienced, loss of coordination and ecological death occurs at 15 to 20 percent loss of body weight. Due to inability to lose more than ca. 500 g of water per hour by panting, javelina cannot maintain a normal body temperature when exposed to a full environmental radiation load during a clear mid-summer day in the desert.

Energy gained in the form of metabolic heat production and absorbed radiation was balanced against energy lost in the form of reradiation, convection, conduction, and respiratory water loss. An energy budget was used to quantify the differences between shaded and unshaded environmental conditions, and the resultant advantages of behavioral selection by the javelina of these different microenvironmental conditions.

The energy balance predicts that the javelina is only able to survive in the desert in the summer by maximum avoidance of the environmental heat load. Avoidance is clearly indicated through primary nocturnal activity and judicious use of both open and shaded portions of the habitat, thereby maximizing heat loss whenever possible, and under certain circumstances using water for evaporative cooling. During summer, use is also made of the relatively cool ground as a heat sink to transfer part of the heat from its body by excavating a shallow depression to lie in.

The inability of the javelina to survive without free water in the summer explains in part its absence from the more arid western portions of the Sonoran Desert, and further accounts for its more "tropical" distribution within the North American Desert.

Water required for thermoregulation if not replenished produces a loss of thermoregulatory ability accompanied by a salt imbalance which appears to be the ultimate cause of death. The salt imbalance manifests itself in the form of loss of coordination followed shortly by convulsions.

APPENDIX

CALCULATIONS OF ENERGY BALANCE

Metabolic Rate

$M = 70\ W^{0.75}$, $W = 29.5$ kg.

$M = (70)(29.5)^{0.75} = (70)(12.65) = 886$ kilocalories/day.

886 kilocalories/day x 1 day/24 hours = 36.9 kilocalories/hour.

$M = 36{,}900$ (37,000) calories/hour.

Absorbed Radiation

$$Q_{abs} = \frac{(a)(2/\pi)(S) + (a)(s) + (a)(r)(S+s) + R_a + R_g}{2}$$

a = absorbtivity = 0.70, π = pi = 3.1416, r = reflectivity = 0.30

1200-1300, in sun

S = solar beam = 1.33 ly/min, s = reflected solar radiation = (.06)(.84) = .05 ly/min, R_a = thermal sky radiation = (2.17 - 1.38) = 0.79 ly/min, R_g = thermal ground radiation = $\varepsilon\ \delta\ T^4$, ε = emmissivity of soil = 0.9, δ = Stefan-Boltzman constant = 8.13×10^{-11}, T = surface temperature of soil (°K), $R_g = (.9)(8.13 \times 10^{-11})(333^4) =$ .900 ly/min.

$$Q_{abs} = \frac{(.7)(.636)(1.33) + (.7)(.05) + (.7)(.3)(1.33 + .05) + .79 + .90}{2}$$

$$Q_{abs} = \frac{.591 + .035 + .290 + .79 + .90}{2}$$

$$Q_{abs} = \frac{2.606}{2} = 1.303 \text{ ly/min}$$

1200-1300, in shade

$S = 0$, $s = (.06)(1.08) = .06$ ly/min, $R_a = (1.08 = .06) = 1.02$ ly/min,

$R_g = (.9)(8.13 \times 10^{-11})(309.5^4) = .700$ ly/min.

$$Q_{abs} = \frac{(.7)(.636)(0) + (.7)(.06) + (.7)(.3)(0+.06) + 1.02 + .70}{2}$$

$$Q_{abs} = \frac{1.773}{2} = .887 \text{ ly/min}$$

2400-0100, unshaded

$S = 0$, $s = 0$, $R_a = .577$, $R_g = (.9)(8.13 \times 10^{-11})(301^4) = .600$ ly/min.

$$Q_{abs} = \frac{(1.0)(.636)(0) + (.7)(0) + (.7)(.3)(0 + 0) + .577 + .600}{2}$$

$$Q_{abs} = \frac{1.177}{2} = .589 \text{ ly/min}$$

2400-0100, shaded

$S = 0$, $s = 0$, $R_a = .647$, $R_g = (.9)(8.13 \times 10^{-11})(298.3^4) = .580$ ly/min.

$$Q_{abs} = \frac{.647 + .580}{2} = \frac{1.227}{2} = .614 \text{ ly/min.}$$

Reradiation of Javelina

Reradiation $= \varepsilon \delta T_r^4$

ε = emmissivity of javelina = 1.0, δ = Stefan-Boltzman constant = 8.13×10^{-11}, T_r = radiant temperature of the javelina ($^\circ$K)

1200-1300, in sun

$T_r = 45^\circ C = 318^\circ K$

Reradiation $= (1.0)(8.13 \times 10^{-11})(318^4) = .831$ ly/min

1200-1300, in shade

$T_r = 40^\circ C = 313^\circ K$

Reradiation = .780 ly/min

2400-0100, unshaded

$T_r = 30^\circ C = 303^\circ K$

Reradiation = .685 ly/min

2400-0100, shaded

T_r = 30°C = 303°K

Reradiation = .685 ly/min

Convection

Convection = $h_c(T_r - T_a)$, T_r = radiant surface temperature, T_a = ambient air temperature, h_c = coefficient of convection = (6.17×10^{-3}) $(V^{1/3}/D^{2/3})$, V = wind velocity = 105 cm/sec, D = diameter of cylinder = 34 cm., $V^{1/3}$ = 4.72, $D^{2/3}$ = 10.50

$$h_c = \frac{(6.17 \times 10^{-3})\ (4.72)}{(10.50)} = 2.78 \times 10^{-3}$$

1200-1300, in sun

T_r = 45°C, T_a = 41.7°C

Convection = $(2.78 \times 10^{-3})(45 - 41.7) = (2.78 \times 10^{-3})(3.3)$ = .009 ly/min.

1200-1300, in shade

T_r = 40°C, T_a = 36°C

Convection = .011 ly/min.

2400-0100 unshaded

T_r = 30°C, T_a = 27.4°C

Convection = .007 ly/min.

2400-0100, shaded

T_r = 30°C, T_a = 27.5°C

Convection = .007 ly/min.

Heat of Vaporization of Water

E_x = energy required to vaporize a given quantity of water at 38°C.

E_x = 572 calories/gram.

Conduction

$$\text{Conduction} = \frac{KA(T_2 - T_1)}{D}$$

K = thermal conductivity of the fur = 3.6×10^{-3}, A = area of contact of adjacent surfaces = 1 square centimeter, T_2 and T_1 are temperatures of adjacent surfaces, D = thickness of fur conductor = 0.25 cm.

1200-1300 in sun

not calculated (see text).

1200-1300, in shade

$T_2 = 38^\circ C$, $T_1 = 36^\circ C$

$$\text{Conduction} = \frac{(3.6 \times 10^{-3})(1.0)(38 - 36)}{(.25)} = .029 \text{ ly/min}$$

2400-0100, unshaded

$T_2 = 38^\circ C$, $T_1 = 28^\circ C$

Conduction = .145 ly/min.

2400-0100, shaded

$T_2 = 38^\circ C$, $T_1 = 25.3^\circ C$

Conduction = .183 ly/min.

Surface Area

Surface area = $A = 10\ W^{2/3}$

A = area in square decimeters, W = weight = 29.5 kg.

$A = (10)(29.5^{2/3}) = (10)(9.6) = 96\ dm^2$

$96\ dm^2 = 9{,}600\ cm^2$

LITERATURE CITED

Bigler, W. J.
1964. The seasonal movements and herd activities of the collared peccary (Pecari tajacu) in the Tortolita Mountains. Masters Thesis, University of Arizona.

Bohstedt, G. and R. H. Grummer.
1954. Salt poisoning of pigs, J. An. Sci., 3(4):933-939.

Cockrum, E. L.
1960. The recent mammals of Arizona: their taxonomy and distribution. Univ. Arizona Press, Tucson.

Eddy, T. A.
1959. Foods of the collared peccary Pecari tajacu sonoriensis (Mearns) in southern Arizona. Masters Thesis, University of Arizona.

Gates, D. M.
1962. Energy exchange in the biosphere. Harper and Row, New York.

Gier, J. T. and R. V. Dunkle.
1951. Total hemispherical radiometers. Trans. Amer. Inst. Elec. Engrs., 70:339.

Hardy, J. D.
1968. Heat transfer. In L. H. Newburgh, Ed., Physiology of heat regulation and the science of clothing. W. B. Saunders Co., Philadelphia.

Hart, J. S.
1964. Geography and season: mammals and birds. In D. B. Dill, Ed., Handbook of physiology. Sec: 4: Adaptation to the environment. Amer. Phys. Soc., Wash. D.C.

Kleiber, M.
1961. The fire of life. John Wiley and Sons Inc., New York.

Knipe, T.
1956. The javelina in Arizona. Ariz. Game and Fish Dept., Bull. No 2:1-96.

Lowe, C. H. and D. S. Hinds.
1971. Effect of paloverde (Cercidium) trees on the radiation flux at ground level in the Sonoran Desert I. Winter. Ecology (in press).

MacFarlane, W. V.
1964. Terrestrial animals in dry heat: ungulates. In D. B. Dill, Ed., Handbook of physiology. Sec: 4: Adaptation to the environment. Amer. Phys. Soc., Wash. D.C.

Porter, W. P. and D. M. Gates.
1969. Thermodynamic equilibrium of animal with environment. Ecol. Monogr., 39:277-244.

Robinson, K. and D. H. K. Lee.
1941. Reactions of the pig to hot atmospheres. Pro. Royal Soc. of Queensland, 43(9):145-158.

Schmidt-Nielsen, K.
1964. Desert animals--physiological problems of heat and water. Oxford Univ. Press, London.

Schweinsburg, R. E.
1969. Social behavior of the collared peccary (Pecari tajacu) in the Tucson Mountains. Doctoral Dissertation, University of Arizona.

Sellers, W. D.
1965. Physical climatology. Univ. of Chicago Press, Chicago.

Shreve, F. and I. L. Wiggins.
1964. Vegetation and flora of the Sonoran Desert. Vol. I. Stanford Univ. Press, Stanford.

Sowls, L. K.
1966. Reproduction in the collared peccary (Tayassu Tajacu). In Comparative Biology of Reproductions in Mammals. Academic Press, New York.

Taylor, C. R.
1969. The eland and the oryx. Sci. Amer., 220:88-95.

Walker, E. P.
1964. Mammals of the world. Johns Hopkins Press, Baltimore.